RP 68

BEARING BRONZES WITH AND WITHOUT ZINC

By H. J. French and E. M. Staples

ABSTRACT

Based on a study of the wearing properties, hardness, structure, notch toughness, and resistance to deformation at temperatures between 70° and 600° F., the bronzes in the copper corner of the copper-tin-lead system were classified according to the character of the service for which they seemed to be best adapted. A study was also made of the effects of 4 per cent zinc on the properties and applications of these bronzes.

Bronzes with less than about 4 per cent tin were considered to be unsuited for general bearing service, since they had low resistance to deformation and wore rapidly in the absence of lubrication. However, some of these alloys, such as those high in lead, should serve satisfactorily for special service involving low loads.

Bronzes with less than about 5 per cent lead appeared to be suited only for service where lubrication could be maintained. However, they should be applicable with such a restriction to a wide range of service conditions, depending upon the proportions of tin present.

Bronzes containing more than about 5 per cent lead were best able of any of the groups studied to operate for short periods in the absence of lubrication. Bronzes with 15 per cent lead were better in this respect than bronzes with 5 per cent lead, but there were no appreciable advantages apparent in raising the lead above about 15 per cent.

The addition of 4 per cent zinc to the copper-tin-lead alloys had, in general, a small influence upon the properties of the bronzes studied. With two exceptions, such changes as were observed seemed beneficial rather than detrimental for bearing service since they comprised a tendency toward higher hardness and resistance to deformation under repeated blows, lower friction, and also lower wear in the absence of oil.

Further development of methods of test for wear in the presence of lubricants may show that zinc tends to increase the weight losses and duration of the "wearing-in" period of bronze bearings, but since this is also a function of the perfection of fit such effects would be disadvantageous only in certain cases.

In general, the results seemed to justify the conclusion that the effects of zinc up to 4 per cent are generally small and may be insignificant in comparison with changes in properties quite readily produced in bronzes from variations in foundry practice. This should not be construed to apply to additions of zinc when other impurities are present.

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I. INTRODUCTION

Within the past three years an extended study was made, in cooperation with the Chicago Bearing Metal Co. and the Magnus Co., of Chicago, Ill., of the wear and mechanical properties of copper-tin-lead alloys widely used in railroad bearings. As already reported,[1] this study was made with the twofold purpose of developing a laboratory testing technique for bearing metals and of finding reasons for the wide variations in the specifications of different carriers for bearings for similar conditions of service.

The testing technique developed in the investigation did not define completely all those properties of importance for alloys intended for service in bearings, but the methods used can properly form part of a more complete testing technique, since they gave information consistent with practical experience. Therefore, more extended application is justified.

Comparisons of the different alloys were based on wear tests, single-blow impact tests on notched bars, repeated pounding tests, tension or hardness tests and microscopic examination. The wear tests were made in the Amsler wear-testing machine, and in addition to determination of weight losses, attention was given to the frictional properties (torque in the tests) and the character of the worn surfaces. Wear tests were made in the presence of a lubricant at atmospheric temperatures, and tests were also made without lubrication at atmospheric and elevated temperatures up to and including 350° F. With the exception of the hardness tests, made only at atmospheric temperatures, the various mechanical tests were carried out at temperatures up to and including 600° F.

[1] H. J. French, S. J. Rosenberg, W. LeC. Harbaugh, and H. C. Cross, Wear and Mechanical Properties of Some Railroad Bearing Bronzes at Different Temperatures, B. S. Jour. Research, 1 (RP. 2); September, 1928; also Proc., Am. Soc. Test. Matls.; 1928.

The copper-tin-lead alloys previously studied were made from commercially pure raw materials, but it is seldom practicable for economic reasons to produce bearing bronzes on a commercial basis wholly from new or "virgin" metals. The largest part of the bearings now manufactured is made of remelted bearings combined with varying amounts of shop scrap and only sufficient new metal to bring the mixtures to the required compositions.

The scrap charged in the form of unserviceable bearings is generally gathered from a multitude of sources, and not only varies in the proportions of copper, tin, and lead but also in the proportions of impurities present, such as zinc, antimony, phosphorus, iron, or nickel, etc.

The subject of impurities is, then, of primary importance in the commercial production of bearing bronzes, and specifications indicate a wide difference of opinion with respect to the maximum allowable limits for different elements. An example is found in comparison of two specifications for the well-known alloy containing 80 per cent copper, 10 per cent tin, and 10 per cent lead. As shown in Table 1, the tentative specifications of the American Society for Testing Materials for sand castings permit a maximum of 0.25 per cent zinc, while the specifications of a prominent carrier call for a zinc content between 1 and 3 per cent.

TABLE 1.—*Comparison of two specifications for bronzes containing 80 per cent copper, 10 per cent tin, and 10 per cent lead*

Element	A. S. T. M. (B-74-28 T)	Illinois Central R. R. Co.	Element	A. S. T. M. (B-74-28 T)	Illinois Central R. R. Co.
	Per cent	*Per cent*		*Per cent*	*Per cent*
Copper	79-81	79-81	Phosphorus	[1] 0.25	[1] 0.25
Tin	9-11	9-11	Aluminum	None.	----------
Lead	9-11	9-11	Sulphur	[1] .05	----------
Zinc	[1] .25	1-3	Antimony	[1] .25	----------
Iron	[1] .10	----------	Other elements	[1] .15	[1] .50
Nickel	[1] .50	----------			

[1] Maximum.

Lack of information on the effects of common impurities and the wide variations in the proportions of copper, tin, and lead specified by different purchasers for bearing metals intended for similar service resulted in the establishment of a research associateship at the National Bureau of Standards by The Bunting Brass & Bronze Co., Toledo, Ohio, for the purpose of studying the properties and applications of bearing bronzes. The tests here reported constitute the first phase of a study of this subject and relate to the properties of copper-tin-lead alloys widely used in bushings in the automotive and other industries, and to the effect of zinc on such bronzes.

II. ALLOYS STUDIED

Most of the compositions tested were selected from the group regularly manufactured by The Bunting Brass & Bronze Co. Some other alloys were included to secure a more general distribution over the copper corner of the copper-tin-lead system and thus permit comparisons on the basis of ternary diagrams. However, in most cases due regard was given in the selections to the industrial production requirements.

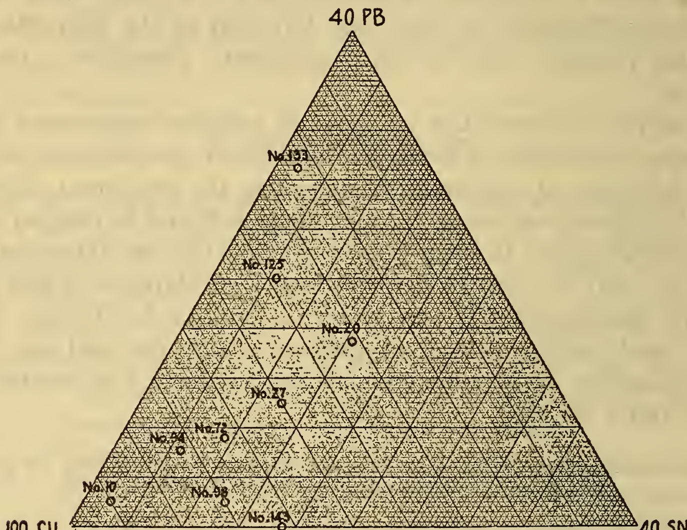

FIGURE 1.—*Ternary diagram showing location of the bronzes tested*

Two groups of alloys were prepared. The first comprised alloys of copper, tin, and lead of compositions shown in Figure 1. In the second group the copper-tin-lead ratios were kept the same, and 4 per cent of zinc was added.

It was, of course, not practicable to adhere exactly to the intended compositions in the production of the test castings, but the deviations encountered can be neglected since comparisons are based largely upon the trends in the copper-tin-lead and copper-tin-lead-zinc systems. The chemical compositions of the different test castings are summarized in Table 2.

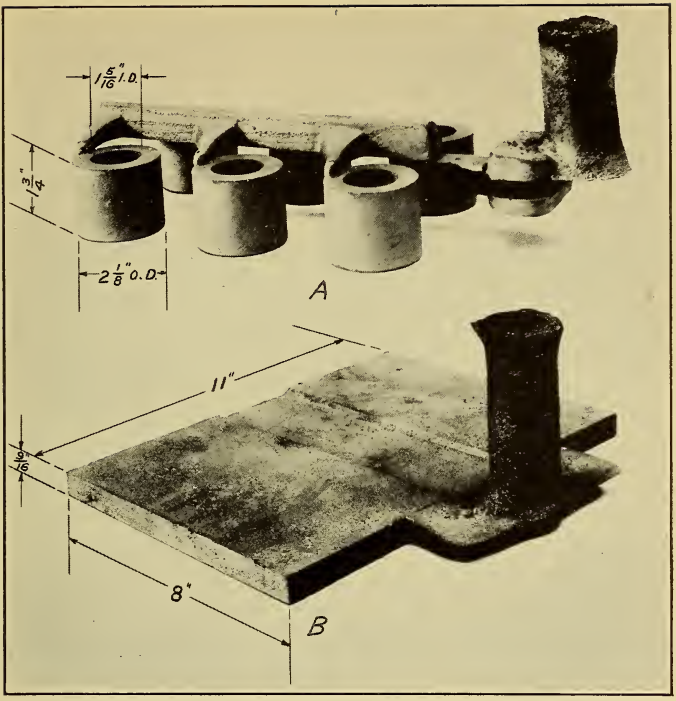

FIGURE 2.—*Test castings used*

A, for the wear-test specimens.
B, for the impact, pounding and hardness tests.

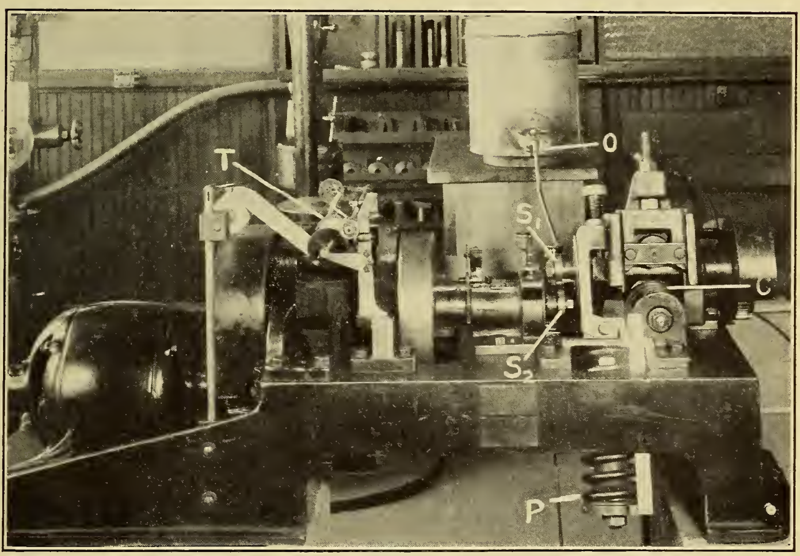

FIGURE 3.—*Amsler wear testing machine used*

Surfaces of specimens S_1 and S_2 move in the same direction but at different speeds, with lateral oscillation produced by cam *C* and under contact pressures controlled by spring *P*. The friction is recorded on the torque indicator *T*. In tests with lubrication the oil is supplied from reservoir *O*. In all tests the total load between specimens was 37.5 pounds; the slip, 12 feet per minute; the amplitude of lateral oscillation, 0.3 inch.

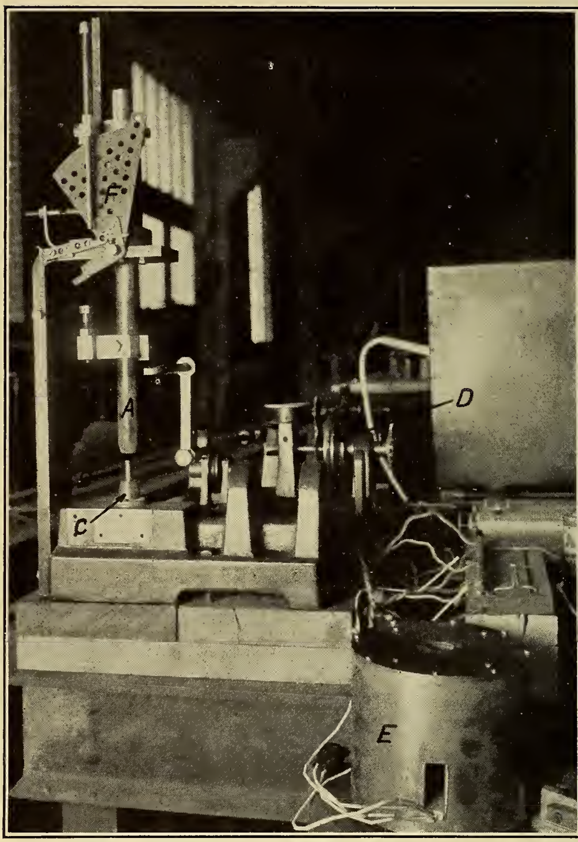

FIGURE 4.—*Equipment used in the repeated pounding tests*

Specimen *B*, on anvil *C*, is subjected to repeated blows in compression by the falling weight *A*. Furnace *E*, mounted on anvil *C*, is used for tests at elevated temperatures. *D* is the driving mechanism and *F* prevents auxiliary blows from rebound of *A*.

Tests made with a weight of 7.15 pounds falling through a distance of 2 inches.

TABLE 2.—*Chemical compositions of bronzes tested*

Alloy No.	Chemical composition [1]					Used for wear tests (W) or mechanical tests (M)
	Cu	Sn	Pb	Zn	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
10 [2]	96.5	1.8	1.8		100.1	W
10	95.4	2.1	2.0		100	M
10Z [2]	91.4	2.0	1.9	4.5	99.8	W
10Z	92.5	2.0	1.8	[3] 3.7	100	M
20 [2]	73.7	11.8	14.4		99.9	W
20	73.1	12.8	14.1		100	M
20Z [2]	69.4	12.1	15.1	3.2	99.8	W
20Z	70.5	11.9	13.8	[3] 3.8	100	M
27	80.4	10.0	9.5		99.9	W
27	79.8	10.3	9.6		99.7	M
27Z	76.5	9.4	9.8	4.1	99.8	W
27Z	76.4	10.1	9.1	[3] 4.4	100	M
27 [2]	80.5	9.8	9.6		99.9	W
27Z [2]	77.4	9.0	10.1	3.3	99.8	W
72	85.8	7.3	6.8		99.9	W
72	85.3	7.3	7.2		99.8	M
72Z	82.2	6.8	7.0	4.0	100	W
72Z	82.5	7.2	6.7	[3] 3.6	100	M
94	89.3	4.5	6.2		100	W
94	89.6	4.8	5.6		100	M
94Z	85.3	4.8	5.8	4.1	100	W
94Z	85.6	4.6	5.8	[3] 4.0	100	M
96	88.1	10.0	2.0		100.1	W
96	88.4	10.3	1.5		100.2	M
96Z	83.9	9.3	2.1	4.4	99.7	W
96Z	84.8	9.5	2.0	[3] 3.7	100	M
96 [2]	88.5	9.5	2.0		100	W
96Z [2]	84.8	9.9	2.1	3.1	99.9	W
125	75.3	4.5	20.1		99.9	W
125	76.6	4.6	18.9		100.1	M
125Z	72.8	4.3	19.1	3.7	99.9	W
125Z	73.0	4.3	18.5	[3] 4.2	100	M
133 [2]	68.8	2.4	28.7		99.9	W
133	75.2	1.5	23.2		99.9	M
133Z [2]	66.3	2.2	27.8	3.7	100	W
133Z	71.0	1.4	23.8	[3] 3.8	100	M
143	85.2	14.7			99.9	W
143	84.8	15.0			99.8	M
143Z	81.1	14.5		[3] 4.4	100	W
143Z	82.0	13.8		[3] 4.2	100	M

[1] 24 of the samples were analyzed for P, and Sb; 12 were analyzed for Fe and S; in no case was any one of these elements present in quantities greater than 0.02 per cent.
[2] These castings in addition to those for the mechanical tests were made at the Bureau of Standards; all others were made in the foundries of The Bunting Brass & Bronze Co., Toledo, Ohio.
[3] Zinc by difference.

III. PREPARATION OF THE TEST CASTINGS

The test castings were of relatively thin sections to give structures and properties comparable to those found in the small bushings so widely used in the automotive industries. Castings for the wear-test specimens were hollow cylinders, while those used for the impact, pounding, and hardness test specimens were in the form of plates as is shown in Figure 2.

The method of preparation of the castings was substantially as follows: Approximately 1,400 pounds of copper (trolley) wire was

melted in a gas-fired furnace under a covering of limestone and borax. About 8 per cent of tin was added to the copper when melted, and, after thorough stirring, the metal was cast into small notched ingots which were used as the basis of the melts for the test castings. These ingots were melted in a small gas-fired crucible furnace, together with the required amounts of copper, tin, and lead under a limestone-borax slag. Zinc when required was added after skimming the metal. All the castings were made in sand molds. Casting temperatures were measured with chromel-alumel thermocouples and a potentiometer.

The metal was poured at approximately 2,000° F. except in the case of alloys Nos. 10 and 133. (Table 2.) A somewhat higher pouring temperature (around 2,100° F.) was required to fill the molds with sound metal with alloy No. 10 containing 96 per cent copper and 2 per cent each of tin and lead.

The large amount of lead (28 per cent) in alloy 133 made necessary the use of a somewhat lower pouring temperature, estimated around 1,950° F., in order that the copper-tin solution would freeze in the mold before the lead had a chance to segregate to any great degree. In all cases the metal was stirred continuously from the time the crucible was removed from the furnace until the metal was ready to pour.

IV. METHODS OF TEST

Metals used as bearings are subjected to a wide range of conditions in service. Failures occur by wear or by inability to carry the required loads, to withstand impact, or to resist deformation ("pounding out"). In addition to these properties, consideration should be given to the frictional properties (for example, starting torque), ability to operate at elevated temperatures, ease of manufacture, and other characteristics.

The conditions encountered in practical service are seldom simple. Most often they are such that the selection of the bearing metal is a compromise to obtain the best combination of properties. The development of a testing technique which permits a logical selection for the varied conditions of practical service is therefore not simple. The situation is further complicated by the fact that the study of the wear of bearing metals can not be divorced from that of lubrication, since most bearings are designed for service in the presence of oils, greases, or other lubricants. The conditions of lubrication encountered industrially vary from so-called complete film lubrication to practically no lubrication at all.

In this investigation wear tests were made both in the presence and absence of oil, as these relate to extreme conditions. The resistance to deformation was studied by repeated pounding tests and the brittleness by single blow impact tests on notched bars. Since

bearings are often required to operate at temperatures above atmospheric, the different tests were made at elevated as well as at atmospheric temperatures.

These methods of test are the same as those previously used and have already been described in detail.[2] Photographs of the equipment used, together with brief descriptions of the principles of operation, are given in Figures 3, 4, and 5.

Objections have been raised to the described methods of test on the basis that correct design can make the properties of the metals of construction for bearings of minor importance. Some engineers usually also favor tests of full-size bearings under practical conditions of lubrication and question the usefulness of wear tests made without lubricants.

The properties of the metals of construction for bearings probably are of minor importance in cases where complete film lubrication can be guaranteed and where also design can reduce service stresses. However, the achievement of this ideal is not always practicable for economic or other reasons, and the properties of the metals of construction still demand consideration.

While the selected methods of test do not completely characterize those properties of interest in bearing-metal applications and probably can not be justly used for fine discriminations they should enable classification of groups of metals in a way which will eliminate large numbers of alloys from consideration when attempting to select metals for definite types of service. Final selection can then be made from a smaller group by actual service tests or in other ways. In fact, the data to be discussed in this report have already been used successfully in this manner.

While questions relating to methods of test were discussed at some length in the report of preliminary work, already referred to, it may be well to point out again that two of the principal points of contention concerning the work to be reported relate to the usefulness of dry-wear tests and the adaptability of the Amsler wear testing machine to the study of bearing metals.

As has been pointed out already, the conditions of lubrication encountered industrially vary from so-called complete film lubrication to practically no lubrication at all. Quite probably much of the wear produced in practical service occurs during periods of so-called boundary lubrication. Since this is essentially an unstable condition of lubrication it does not appear practicable at this stage of the development of wear testing to obtain reproducible results under conditions of boundary lubrication. Wear is not an important factor in the presence of complete film lubrication, and therefore it seems logical to use tests without lubricants as the base line for

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[2] See footnote 1, p. 1018.

present comparisons and the development of a more complete testing technique. Furthermore, the results so far obtained have in most respects been generally consistent with practical experience.

The selection of the Amsler wear-testing machine in which it is practicable to approach line contact between the bearing and shaft metals is justified by the elimination of the factor of fit. In the suggested tests of full-size bearings it is difficult to eliminate variations from the factor of fit, by which is meant variations in the initial smoothness of the contact surfaces and how well these conform one to the other. It is known that variations from these sources

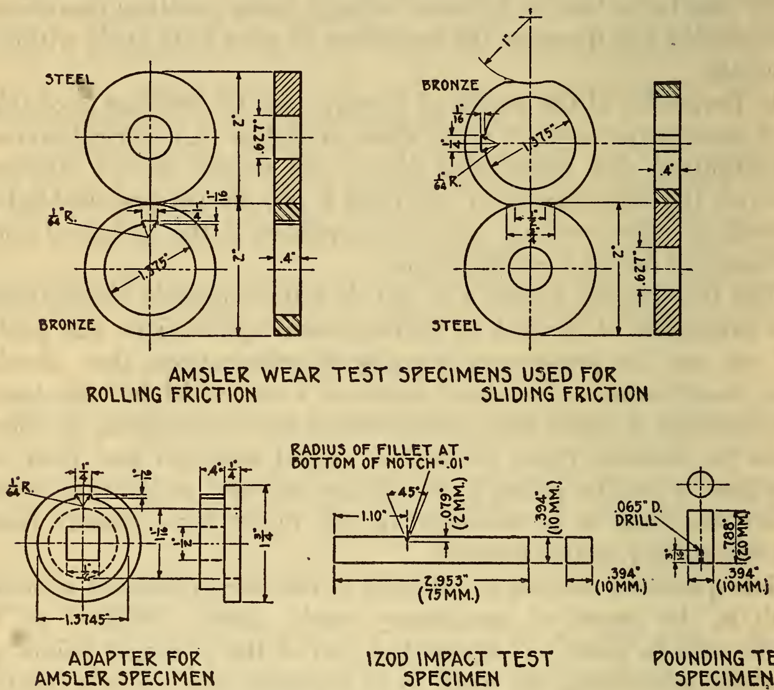

Figure 6.—*Test specimens used*

can materially affect the amounts and rates of wear, and the results of tests of full-size bearings are more often indicative of the manner of installation or the conditions of lubrication than of the performance of the metals.

Further development and perfection of the methods of test used in this investigation can be expected to throw further light upon justifiable interpretations of the results, but for the present the principal use of the data, and the only one recommended, is the grouping of the metals according to the broad classes of service for which they are best adapted.

The steel specimens which, for the previous wear tests, were cut from used medium carbon-steel railroad axles were replaced by

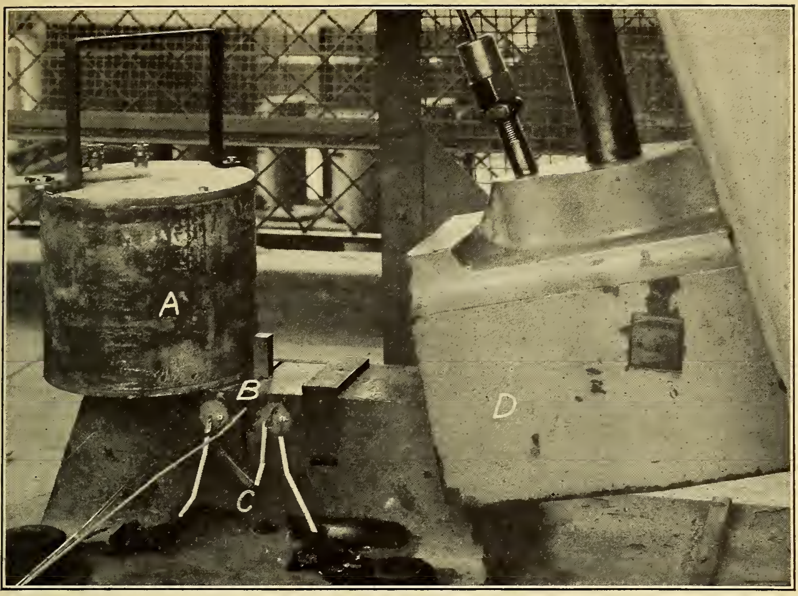

FIGURE 5.—*Part of the equipment used in the notched-bar (Izod) impact tests*

Specimen *B* is subjected to a blow from tup *D* immediately after removal of equalizing furnace *A*. The coils, *C*, permit the vise to be brought to the temperature of furnace *A*.

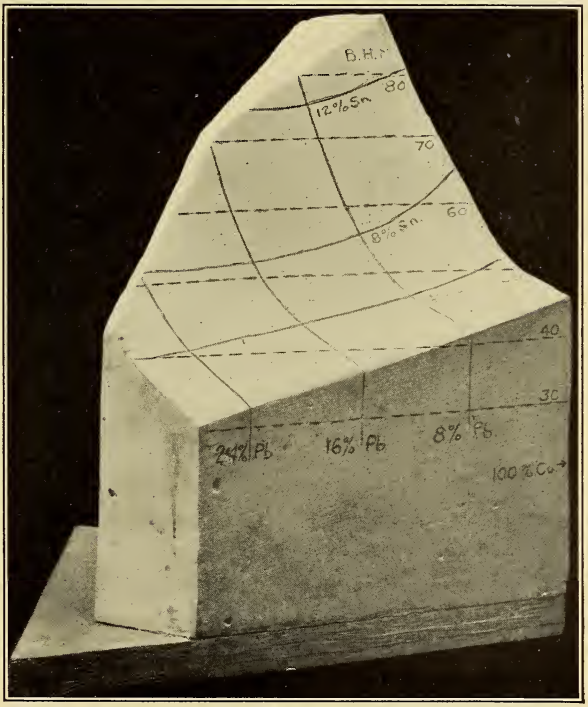

FIGURE 7.—*Approximate Brinell hardness values for part of the system copper-tin-lead*

Based on tests with a 10-mm ball and a 500-kg load

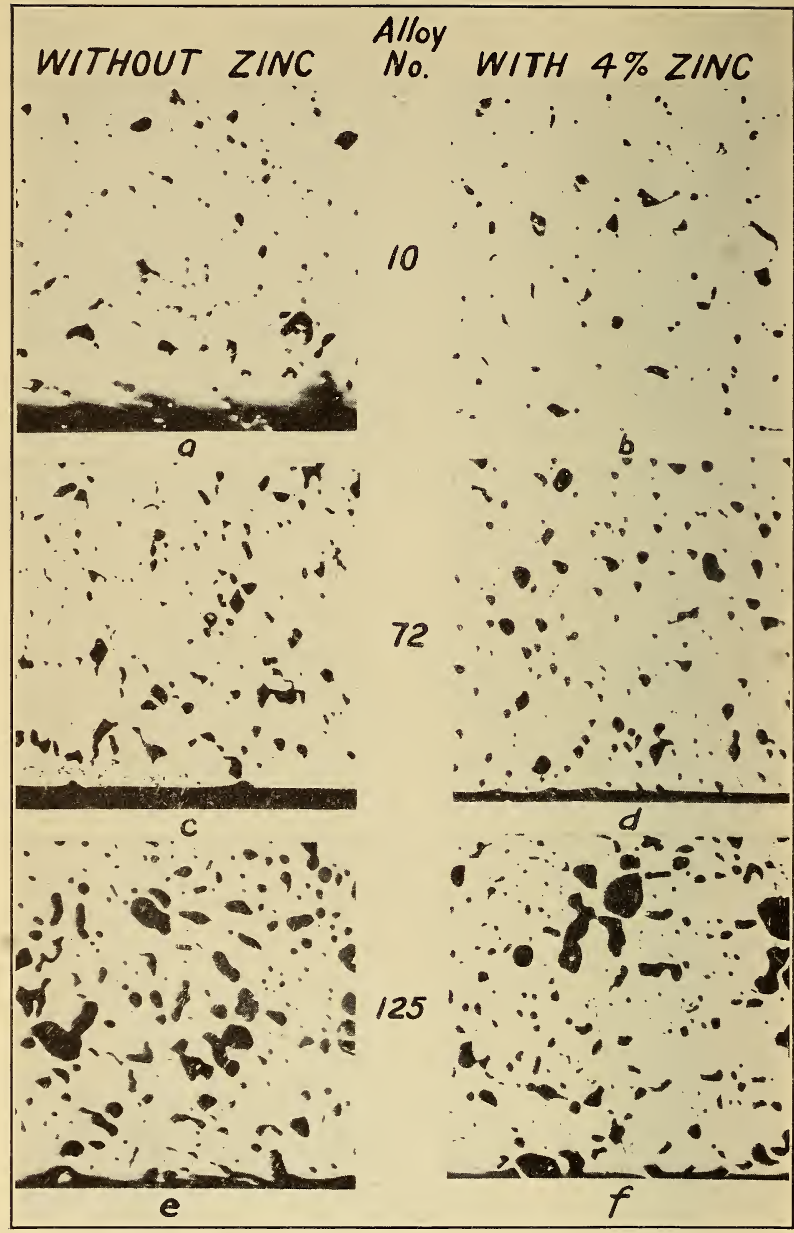

FIGURE 8.—*Unetched sections of some of the bronzes tested.* $\times$ *100*

Alloy No. 10, nominally 96 per cent Cu, 2 per cent Sn, 2 per cent Pb.
Alloy No. 72, nominally 85.4 per cent Cu, 7.3 per cent Sn, 7.3 per cent Pb.
Alloy No. 125, nominally 75.5 per cent Cu, 4.5 per cent Sn, 20.0 per cent Pb.

hardened steel of the composition and heat treatment shown in Table 3.

TABLE 3.—*Composition and heat treatment of steel used in the wear tests*

	Per cent
Carbon	0.93
Manganese	1.11
Silicon	.20
Chromium	.32
Tungsten	.36

Heat treatment:
  1,500° F., 30 minutes quench in thin oil.
  350° F., 1 hour quench in thin oil.
Rockwell "C" scale hardness after treatment, 61 to 63.

The selection of this steel was the result of a careful survey by The Bunting Brass & Bronze Co. of the applications of their bushings. A wide difference was found in the shafting materials, but in a majority of cases hardened steels were employed. Casehardened low-carbon steels were most often used, but as difficulties were anticipated in reproducing results with casehardened low-carbon steel specimens, the oil-hardening steel (Table 3) was selected. This selection was based on comparable surface hardness, and is considered to represent the steel contact surfaces encountered in very many of the practical applications of the bearing bronzes studied.

The test specimens used in the different tests are shown in Figure 6. They are similar to those employed in previous work, with the exception of the specimen for the repeated pounding tests, which had a ratio of length to diameter of 2 instead of 2.5. This change reduced bending of the specimens and resulted in more consistent results at large deformations.

V. EXPERIMENTAL RESULTS

1. HARDNESS AND STRUCTURE OF Cu-Sn-Pb ALLOYS

The tests on the copper-tin-lead alloys without zinc confirmed the results of previous tests [3] on a narrower range of compositions and make possible a classification of alloys over a considerable area of the copper corner of the copper-tin-lead ternary diagram. Solid models are used as the basis for discussion, since these offer a convenient means of indicating the trends produced by combined variations in the proportions of copper, tin, and lead. In these models the position of any point on the triangular base represents the chemical composition, while the height represents the particular property under discussion. General trends are shown without emphasizing

[3] See footnote 1, p. 1018.

minor variations, which are of no great practical importance and probably associated with experimental errors.

As shown in Figure 7, the hardness of the bronzes increased with increase in the proportions of tin, particularly when the alpha solid solubility of tin in copper was exceeded. For the conditions encountered in the preparation of the test castings the limit of this solubility was at about 9 per cent tin in copper, as will be evident from examination of the micrographs of Figure 9. As the lead in the bronzes increased the hardness decreased, whether the bronzes contained large or small proportions of tin. These characteristics are well known, and Figures 7, 8, and 9 are given merely as a record of the hardness and structures of the particular castings tested.

2. WEAR WITH AND WITHOUT A LUBRICANT

Before discussing the results of other tests it should be recalled that difficulties were encountered in earlier work in attempting to define the wearing properties of bronzes by tests in the presence of lubricants. These difficulties were due partly to the fact that with what was probably complete film lubrication the metals were not in continuous and direct contact and the wear dropped to such low rates after an initial "wearing-in" period that it became impracticable to differentiate with any degree of certainty between the various metals. As previously stated, there are not at present available well-defined methods for making wear tests under the unstable conditions of so-called "boundary lubrication" where wear is liable to occur in practical service, and, accordingly, the wear tests upon which the major comparisons were based were made dry: that is, in the absence of the customary lubricants.

Such tests gave only a partial picture of the wearing properties of the bronzes tested in the previous investigation and therefore further efforts were made to secure interpretable data from wear tests made in the presence of oil. Tests were continued for long periods, and the slopes of the wear-revolution and wear-work curves subsequent to the "wearing-in" period (illustrated in fig. 10) are used as the basis of Figure 11.

However, these tests can not justly be given as much weight as those made without oil, since the differences in duplicate determinations (Table 4) were more nearly of the order of magnitude of the differences between different bronzes than was the case in the dry-wear tests. This is due to the fact that in the dry-wear tests the bronzes quickly showed fairly constant and relatively high rates of wear, while in the presence of oil the first rapid wear was followed by decreases to very low wear rates. (Fig. 10.) Furthermore, while the tests with oil were continued for periods four to seven times as

long as those required to reach an actual or apparent state of equilibrium in the dry-wear tests, it is not known whether further decreases in the wear rates and a practical elimination of the differences between the different bronzes would result if the tests in the presence of oil were continued for even longer periods.

TABLE 4.—*Summary of the results of wear tests with lubrication*

BRONZES WITH LESS THAN 5 PER CENT LEAD

Lot No.	Chemical composition				Rate of wear after initial period, weight loss per—		Total number [1] of revolutions (in thousands)	Total [1] work done (in 1,000 m kg)	Total [1] weight loss (in g)
	Cu	Sn	Pb	Zn	1,000 m kg	10,000 revolutions			
	Per cent	*Per cent*	*Per cent*	*Per cent*					
11D3	85.2	14.7			0.0019	0.0021	100	10.6	0.07
11D4	85.2	14.7			.0026	.0033	160	19.0	.45
12D3	81.1	14.5		4.4	.0027	.0039	340	47.6	1.05
7D3	88.1	10.0	2.0		.0031	.0033	120	14.6	.15
15D3	96.5	1.8	1.8		.0028	.0032	90	10.2	.05
16D3	91.4	2.0	1.9	4.5	.0031	.0042	330	43.8	.89
Average					.0027	.0033			

BRONZES WITH 5 TO 12 PER CENT LEAD

Lot No.	Cu	Sn	Pb	Zn	1,000 m kg	10,000 revolutions	Total number of revolutions	Total work done	Total weight loss
1D3	80.4	10.0	9.5		0.0025	0.0027	120	13.9	0.11
3D3	85.8	7.3	6.8		.0034	.0042	120	14.3	.25
3D4	85.8	7.3	6.8		.0017	.0022	120	15.3	.33
5D3	89.3	4.5	6.2		.0019	.0025	120	14.7	.14
Average					.0024	.0029			

BRONZES WITH 15 PER CENT OR MORE LEAD

Lot No.	Cu	Sn	Pb	Zn	1,000 m kg	10,000 revolutions	Total number of revolutions	Total work done	Total weight loss
17D3	73.7	11.8	14.4		0.0042	0.0052	160	19.3	0.51
18D3	69.4	12.1	15.1	3.2	.0010	.0013	260	34.1	.56
9D3	75.3	4.5	20.1		.0040	.0042	100	11.1	.08
9D4	75.3	4.5	20.1		.0042	.0053	160	19.7	.49
23D3	68.8	2.4	28.7		.0071	.0089	120	13.2	.25
24D3	66.3	2.2	27.8	3.7	.0048	.0060	340	45.0	1.71
Average					.0042	.0052			

[1] When the tests were discontinued.

An adequate testing technique has not yet been developed for wear of bearing bronzes in the presence of lubricants, and while the individual differences shown in Table 4 were disregarded and the average wear rates of groups of bronzes made the basis of the smooth contours of the solid model shown in Figure 11, some definite trends are shown which can justly be considered along with the results of the dry-wear tests.

Aside from the very low rates of wear shown by all the bronzes subsequent to the "wearing-in" period, it will be observed that the high-lead bronzes wore somewhat more rapidly in the presence of oil than did the low-lead bronzes. This is directly opposite to the effects observed in the absence of oil.

The addition of 4 per cent zinc to the copper-tin-lead alloys did not produce outstanding differences in the wear rates subsequent to the "wearing-in" period in the tests made with oil. However, the weight losses and the durations of the "wearing-in" periods were generally greater in the bronzes with zinc than in the corresponding

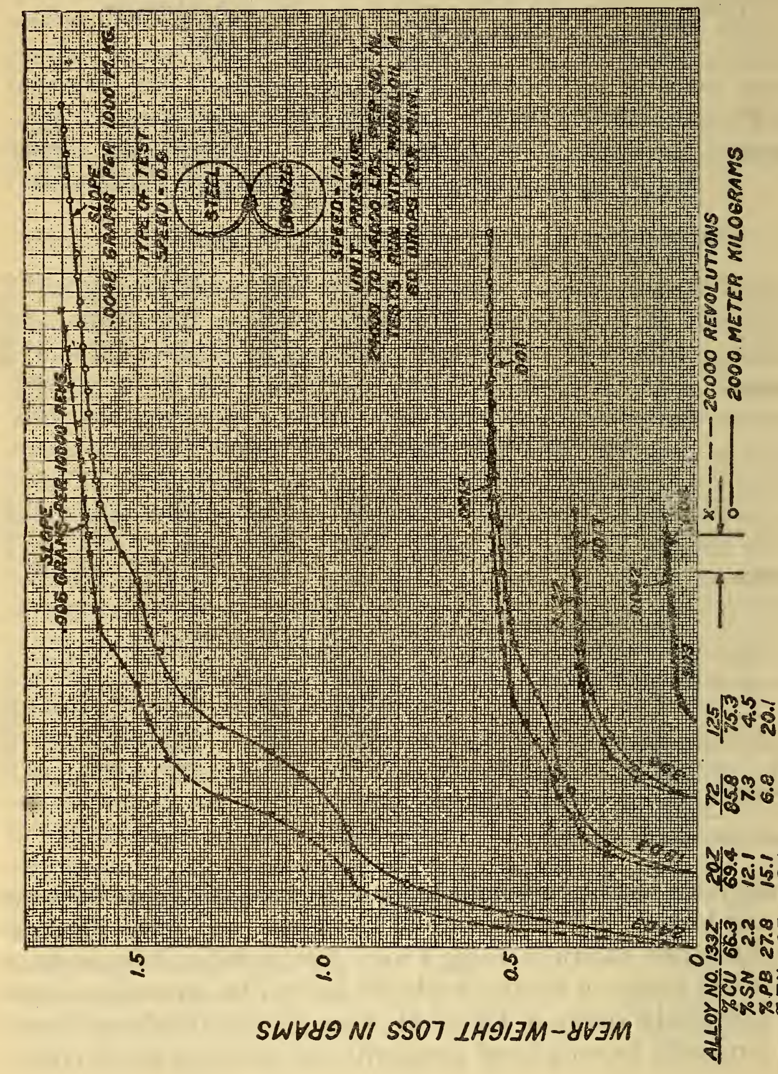

Figure 10.—*Relations between wear, work, and revolutions in wear tests made in the presence of oil*

alloys without zinc. This might be given more weight were it not for the fact that the bronzes with zinc were cast, machined, and tested some months after those without zinc. The "wearing-in" period in tests made in the presence of oil is known to be dependent quite largely upon the smoothness of the original contact surfaces, the oil,

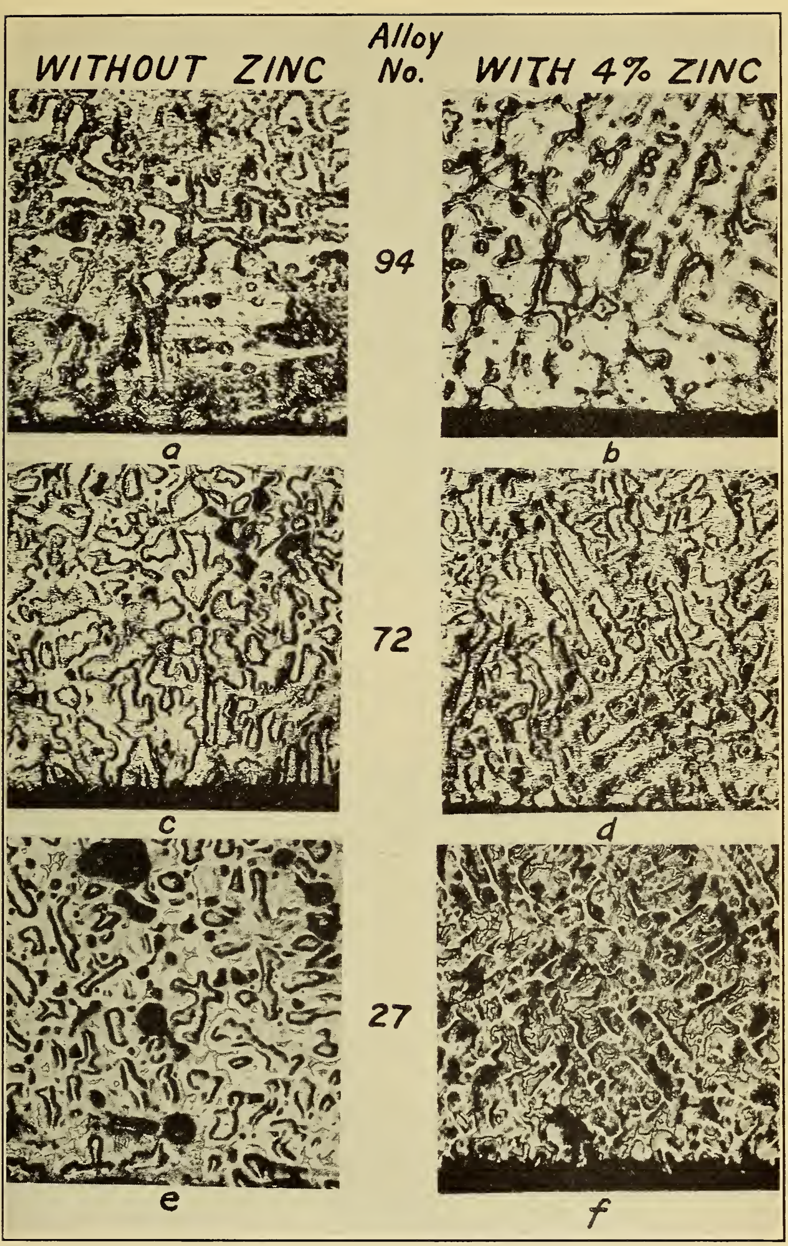

FIGURE 9.—*Micrographs of some of the bronzes tested.* $\times$ *100*

Etched with solution of 3 parts NH_4OH plus 1 part H_2O_2 followed by solution of $FeCl_3$ in HCl. (10 g $FeCl_3$ plus 30 ml conc. HCl plus 120 ml H_2O).
Alloy No 94, nominally 89.4 per cent Cu, 4.5 per cent Sn, 6.1 per cent Pb.
Alloy No. 72, nominally 85.4 per cent Cu, 7.3 per cent Sn, 7.3 per cent Pb.
Alloy No. 27, nominally 80.0 per cent Cu, 10.0 per cent Sn, 10.0 per cent Pb.

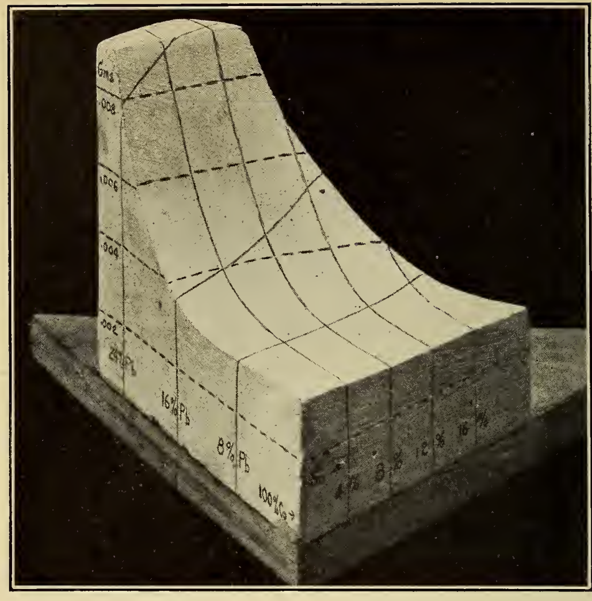

FIGURE 11.—*Wear (subsequent to the "wearing-in" period) of the bronzes tested with lubrication at atmospheric temperatures*

Wear expressed in weight loss per 10,000 revolutions. Conditions of test, including the oil used, are described in detail in the reference given in footnote 1 of the text.

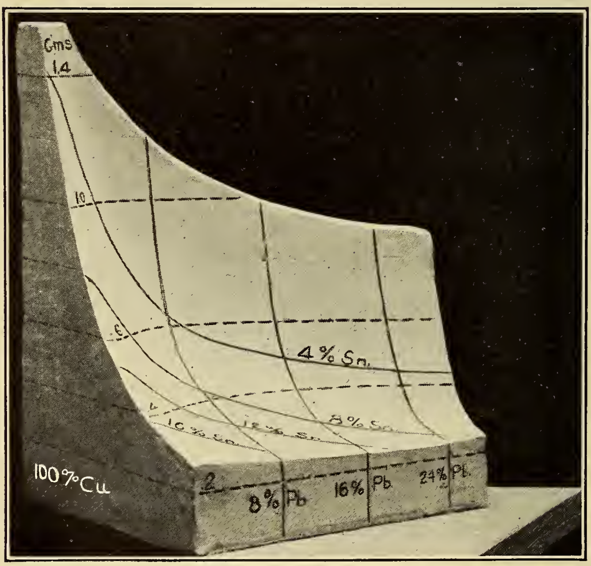

FIGURE 12.—*Wear of the bronzes tested without lubrication at atmospheric temperatures*

Wear expressed in weight loss per 10,000 revolutions. Conditions of test are described in detail in the reference given in footnote 1 of the text.

the metals themselves, and other factors, including contact pressures and rates of slip. Since the bronzes with and without zinc were not all prepared and tested at one time, the described differences in performance may not be the result solely of the additions of zinc.

But even if the results of the wear tests with oil are assumed to establish that zinc tends to increase the weight losses and duration of the "wearing-in" period zinc will not necessarily exert a deleterious effect upon bronzes used in bearings, since the importance of the "wearing-in" period is a function of the fit. The better the fit—that is, the smoother the original surfaces and the better the conformity of bearing and shaft—the less will be the practical importance of the "wearing-in" period and the effects of the zinc.

With the possible exception of variations in the "wearing-in" period, the wear tests made in the presence of oil developed no deleterious effects from the addition of 4 per cent zinc to the copper-tin-lead alloys. In this respect the tests with oil gave similar results to the majority of those tests made without oil, which will be described subsequently in this report.

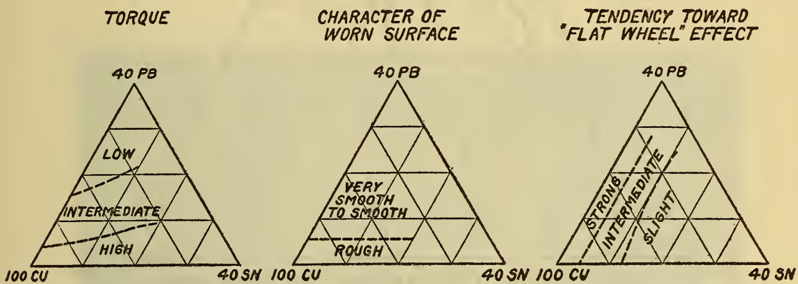

FIGURE 13.—*Special features observed in the wear tests without lubrication at atmospheric temperatures*

3. TRENDS IN THE Cu-Sn-Pb SYSTEM

Figure 12 shows that the rates of wear of the bronzes in the absence of oil were lowered by increase in either tin or in lead. However, the alloys with less than about 4 per cent tin are not well suited for general bearing service, since their wear rates remained relatively high even in the presence of appreciable proportions of lead. As is shown in Figures 13 and 14 (*a*), alloys with less than about 4 per cent tin also showed a strong tendency toward "flat wheel" effects which may be taken to indicate low resistance to deformation. This is confirmed in Figure 15, in which are summarized the results of the repeated pounding tests.

Thus a twofold advantage was gained from the addition of the tin to copper in that the rate of wear was reduced and the strength or resistance to deformation was increased. On the other hand, the cop-

per-tin alloys low in lead had relatively unfavorable frictional properties, as is shown by the high torque values (fig. 13), and also acquired rough-worn surfaces (fig. 14 (*b*)). The worn surfaces of the alloys high in lead were relatively smooth (fig. 14 (*c*)) and the friction was relatively low. Both of these latter characteristics are favorable in preventing damage during any temporary inadequacy in lubrication. High friction will tend to increase the operating temperatures and to accelerate wear and should also promote seizures; rough-worn surfaces may increase tendencies to score the shaft.

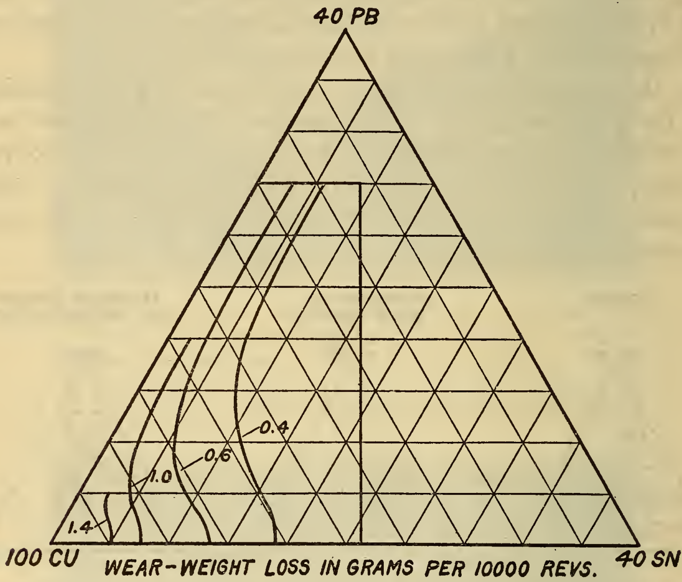

FIGURE 17.—*Contours of the solid model shown in Figure 12*

Conditions of test are described in detail in the reference given in footnote 1 of the text.

While increases in either lead or in tin produced progressive decreases in the wear rates, these metals can not be added in any proportions within the limits investigated without materially affecting other properties of interest in the application of bronzes in bearings. Figure 15 shows that increase in lead had only a minor effect upon the resistance to deformation under repeated blows in compression while tin markedly increased it. However, with more than about 7 or 8 per cent tin, which resulted in the appearance of the alpha-delta eutectoid, there was a general decrease in the notch toughness. (Fig. 16.) In alloys within the solid solution range increase in lead also decreased the notch toughness appreciably, but in the high tin alloys the tin effectively reduced the impact values so that the effect of the increase in lead was not so noticeable.

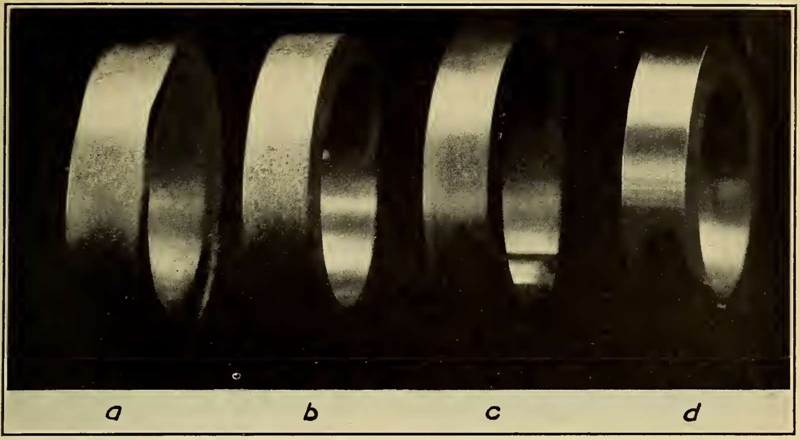

FIGURE 14.—*Photographs of some of the wear-test specimens before and after test*

a, "Flat wheel" condition in one of the bronzes tested (alloy No. 10Z); *b*, Bronze specimen showing rough type of wear (alloy No. 143); *c*, Bronze specimen showing smooth type of wear (alloy No. 20); *d*, Bronze specimen before test (machined surface) (alloy No. 96).

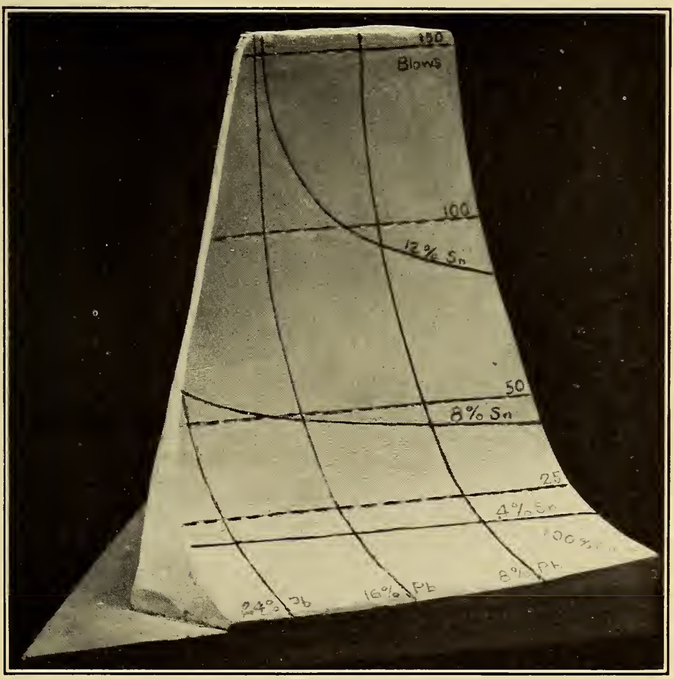

FIGURE 15.—*Resistance to repeated blows in compression of the bronzes at atmospheric temperatures*

Comparisons are based on the number of blows producing 5 per cent deformation

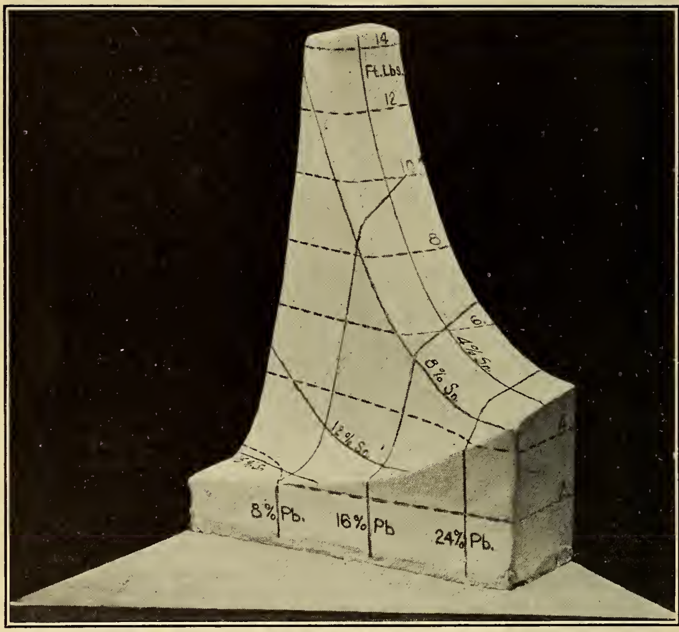

FIGURE 16.—*Izod impact resistance of the bronzes at atmospheric temperatures*

4. PRACTICAL INTERPRETATION OF THE RESULTS FOR Cu-Sn-Pb ALLOYS

Whether or not one composition may be considered to be superior to another is largely a question of the properties necessary to defeat the destructive forces encountered. Figures 17 and 18 show the contour lines of the solid models of Figures 7, 12, 15, and 16, and are included to permit comparisons of the numerical values obtained in the tests of the different alloys

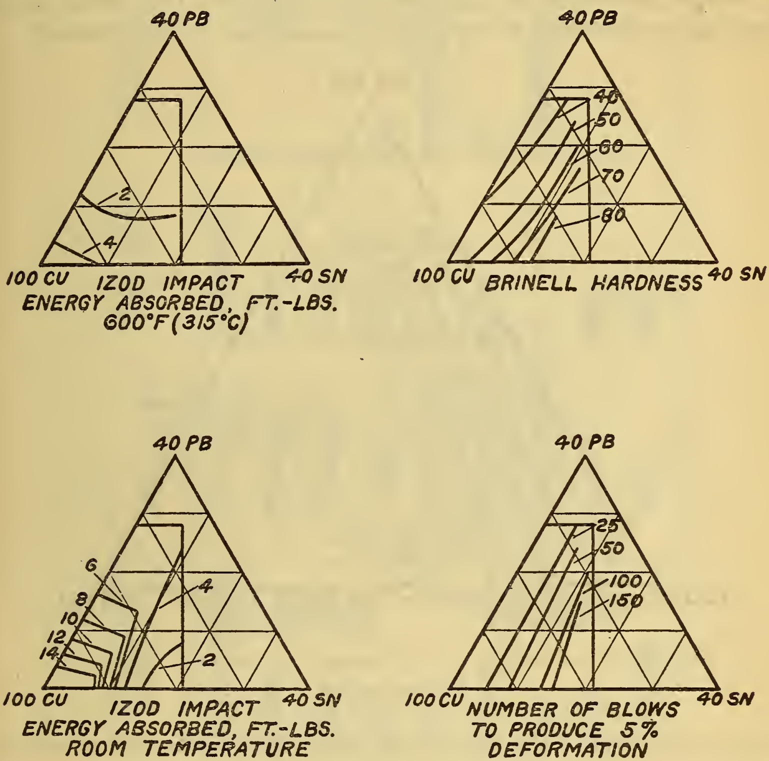

FIGURE 18.—*Contours of the solid models shown in Figures 7, 15, and 16*

From the viewpoint of practical bearing applications the copper-tin-lead alloys may be divided roughly into five groups, as is shown in Figure 19.

Group A.—The first group, comprising alloys with less than about 4 per cent tin, is unsuited for general bearing service, since the alloys had very low resistance to deformation and wore rapidly in the absence of lubrication. Other reasons are shown in the various charts in this report. However, some of these alloys, such as those high in lead, may serve satisfactorily for service involving low loads.

Group B.—This group, comprising alloys with less than about 5 per cent lead and up to about 11 per cent tin, appears to be suited for ordi-

nary conditions of service where neither very high strength nor the ability to operate in the absence of lubrication are required. The alloys were relatively tough, as judged by the Izod impact test, and those with the highest proportions of tin had moderately high resistance to deformation (strength).

Group C.—Alloys in Group C, containing from about 11 to 15 per cent tin and less than about 5 per cent lead, were stronger but had a lower notch toughness than alloys of Group B. They should serve well where resistance to deformation is required but would not be chosen for applications when lubrication can not be maintained.

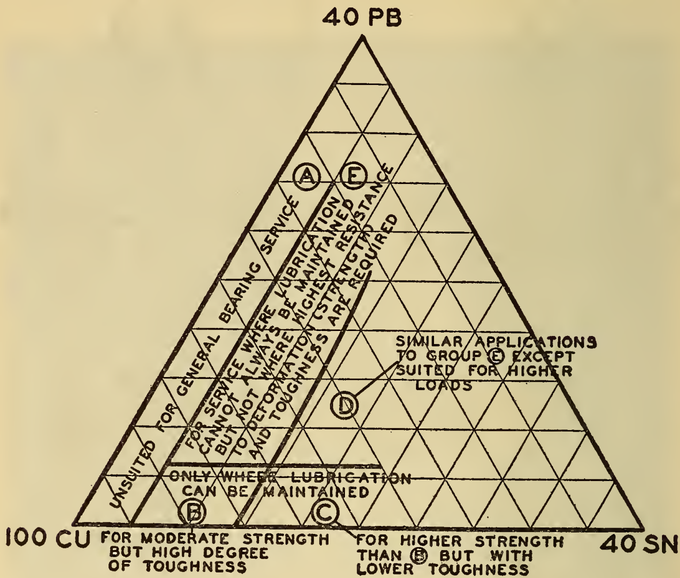

FIGURE 19.—*Grouping of the bronzes for various classes of bearing service*

Failures are more liable to occur at sharp oil grooves under suddenly applied loads than in the case of Group B alloys, expecially those with the lowest proportions of tin.

Groups D and E.—Alloys in these two groups are best able of any of the alloys tested to operate for short periods in the absence of lubrication. They contain from about 4 to 16 per cent tin and from 5 to 30 per cent lead. As a group the alloys did not have a high degree of notch toughness, but they had good resistance to deformation which increased with the proportion of tin. The alloys in these two groups had favorable frictional properties (low torque and smooth worn surfaces), especially when the lead was at the upper limits of the range. High lead tended to reduce the strength and notch toughness, but appreciable variations can be secured in the mechanical properties of the group while maintaining a desirable set of wearing properties.

5. EFFECT OF TEMPERATURE ON THE PROPERTIES OF Cu-Sn-Pb ALLOYS

The data given in support of the preceding discussion were obtained in tests at atmospheric temperatures, but the grouping of the alloys and the general conclusions relating to their fields of application apply, with few exceptions, at elevated temperatures. The results

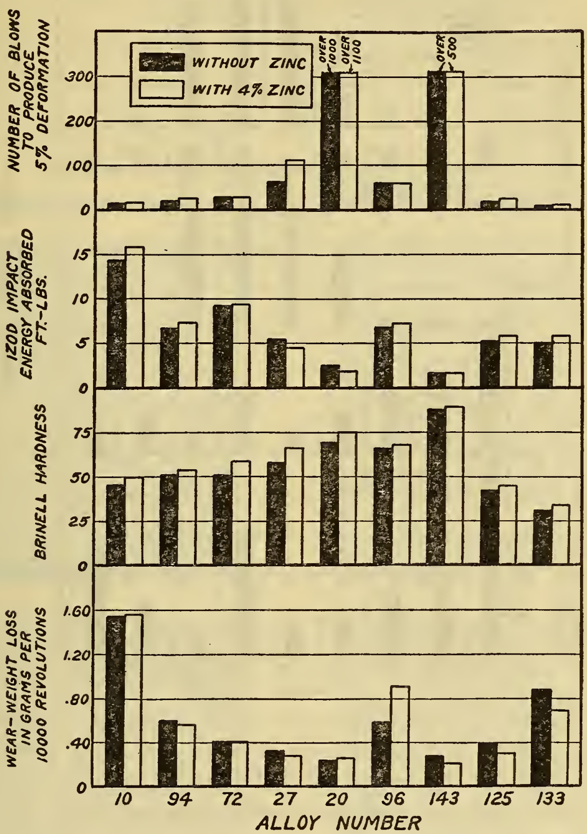

FIGURE 20.—*Comparison of the properties of the bronzes with and without zinc when tested at atmospheric temperatures*

For the chemical compositions of the various bronzes, see Table 2.

of the tests at elevated temperatures differed numerically from those at atmospheric temperatures, but the trends in the copper-tin-lead system were generally similar. Increase in temperature raised the wear rates and lowered the notch toughness, but the pounding resistance was not appreciably affected within the range 70° to 600° F. These features can be substantiated by comparison of Figures 20 and 21.

An important effect of temperature increase was to reduce the notch toughness of all the alloys to very low values. In other words, the differences in Izod impact values between the different alloys at atmospheric temperatures disappeared almost entirely when the temperature was raised to 600° F. (Fig. 18.)

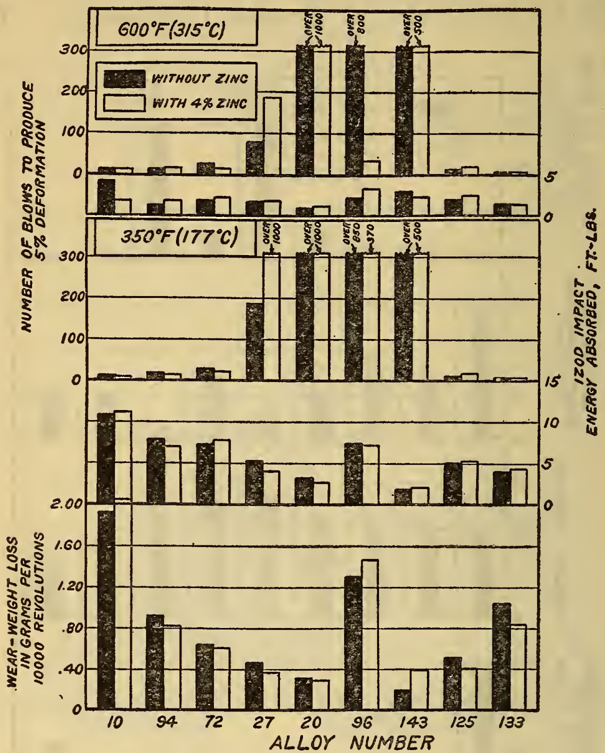

FIGURE 21.—*Comparison of the properties of the bronzes with and without zinc when tested at 350° and 600° F. (175° and 315° C.)*

For the chemical compositions of the various bronzes, see Table 2.

6. EFFECT OF 4 PER CENT ZINC ON THE PROPERTIES OF Cu-Sn-Pb ALLOYS

Zinc when added in small amounts to copper-tin alloys acts as a deoxidizer, and the resultant castings are generally freer from oxides and blowholes than untreated metal. When present in quantities greater than 2 or 3 per cent, zinc is generally considered to have a deleterious effect on the strength and ductility of bronzes. However, copper-tin-zinc alloys are widely used industrially and some have very excellent properties. The work of Hoyt,[4] Guillet and Revillon,[5]

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[4] S. L. Hoyt, On the Copper-Rich Kalchoids, J. Inst. Metals, 10, p. 235; 1913.

[5] L. Guillet and Revillon, Determination of the Coefficient of Equivalence for Special Bronzes, Rev. Met. Mem., 7, p. 429; 1910.

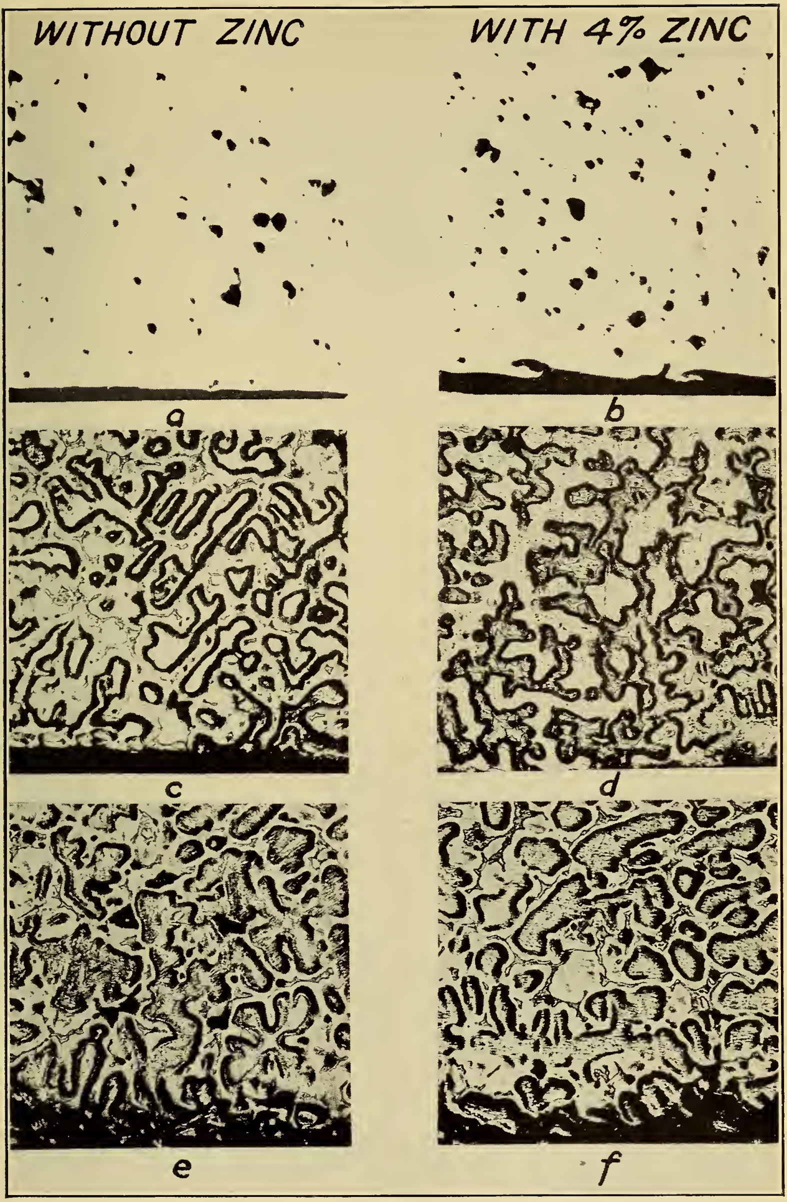

FIGURE 22.—*Micrographs of different melts of alloy No. 96 with and without zinc.* $\times$ *100*

a to *d*, inclusive, are from the first two melts; *e* and *f* are from the third and fourth melts. Etchant for *c* to *f*, inclusive, same as that described in legend for Figure 9.

and Thurston,[6] gives a fairly complete picture of the constitution and properties of alloys in this system, but much less is known of the effect of zinc on the copper-tin-lead alloys so widely used as bearing metals.

Clamer [7] found that the addition of zinc to leaded bronzes hardened the alloys considerably, embrittled them and increased the wear, but he concluded that the alloys having approximately 5 per cent tin, up to 20 per cent lead, and up to 5 per cent zinc should be entirely satisfactory for all classes of car journal bearings.

In studying the copper corner of the copper-tin-zinc system Kuhnel and coworkers [8] found that a copper-base alloy containing 9 per cent zinc and 6 per cent tin was more resistant to wear than one containing 8 per cent tin and 3.5 per cent [9] zinc.

The addition of 4 per cent zinc to the copper-tin and copper-tin-lead alloys previously discussed in this report resulted in the following effects which are shown graphically in Figures 20 and 21.

Hardness.—A measurable but slight increase was produced in the Brinell hardness.

Structure.—The zinc increased the amount of the eutectoid, as will be seen in Figures 9 (*a*) to 9 (*f*) inclusive, and in this respect may be considered to replace tin although not in equal proportions. Zinc also appeared to promote uniformity in the distribution of the lead with respect to both size and location of the particles, but this was evident only in the low-lead bronzes (fig. 8 (*c*) and (*d*)) and not in the high-lead bronzes (fig. 8 (*e*) and (*f*)). Further work would be necessary to establish the magnitude of the effects in this direction.

Impact.—Comparatively minor changes were produced in the Izod impact test values. In some cases the alloys with zinc showed slightly higher impact resistance and in others lower values than the corresponding zinc-free alloys, but the differences were small at all temperatures between 70° and 600° F., and should not affect the selection of any one of the metals for bearing service.

Repeated pounding.—Small changes were observed in the resistance to repeated blows in compression, but the tendency was generally toward an increase in the resistance to deformation at each test temperature including 600° F.

In Figure 21 there is a large difference in the numerical values used in comparing alloy No. 96 with and without zinc at 600° F. This difference is not indicative of a large difference in the resistance to deformation but is the result of the method of comparison employed, which is based on the number of blows producing 5 per cent deformation of the test specimens.

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[6] R. H. Thurston, Materials of Engineering, Pt. III, Brasses, Bronzes. John Wiley & Sons, p. 172; 1900.

[7] G. H. Clamer, Effect of Changes in the Composition of Alloys Used by the American Railways for Car Journal Bearings, Trans. Am. Inst. Metals, 9, p. 241; 1915.

[8] R. Kuhnel, On the Constitution and Properties of Red Brass, Zeit. f. Met., 18, p. 306; 1926; J. Inst. Metals, No. 1, p. 465; 1927.

[9] Both bronzes contained 2 per cent lead and small amounts of nickel and iron.

It so happened that the bronze with zinc deformed about 6 per cent and that without zinc only about 3½ per cent in the first 50 blows. Both then showed evidence of strain hardening, with the result that the bronze without zinc required a very large number of blows to produce 5 per cent deformation. Actually the deformational characteristics of the alloy No. 96 were quite similar with and without zinc, as is shown by the fact that at the end of 1,000 blows the bronze without zinc had deformed 5 per cent and that with zinc 7.5 per cent.

TABLE 5.—*Frictional properties of bronzes with and without 4 per cent zinc as determined in wear tests without lubrication at different temperatures*

TESTS AT ROOM TEMPERATURE

Alloy No.[1]	Total work in 1,000 M kg, done at the end of the first 40,000 revolutions		Alloy No.[1]	Total work in 1,000 M kg, done at the end of the first 40,000 revolutions	
	Alloy without zinc	Alloy with 4 per cent zinc		Alloy without zinc	Alloy with 4 per cent zinc
10	26.5	24.8	96	29.8	26.5
94	22.3	21.8	143	46.6	41.8
72	21.5	21.0	125	18.9	19.5
27	24.1	20.1	133	15.0	14.3
20	23.2	21.8			
TESTS AT 350° F.					
10	[2] 17.5	[2] 15.0	96	21.0	20.0
94	20.5	16.0	143	40.4	36.2
72	18.5	17.2	125	14.0	12.2
27	17.0	16.0	133	14.5	14.5
20	19.0	19.0			

[1] See Table 2 for chemical compositions. [2] For first 30,000 revolutions.

Wear and friction.—The zinc quite generally lowered the friction in the wear tests made without oil, as is indicated by the work values recorded in Table 5, but seemed to exert an irregular influence upon the wear rates. In a majority of cases the weight losses were not appreciably different in the corresponding alloys with and without the zinc, but in alloys Nos. 125 and 133 containing high lead and low tin (2 to 4.5 per cent tin) the zinc produced a definite decrease in the weight losses. On the other hand, in the high-tin low-lead bronzes, Nos. 96 and 143, the addition of 4 per cent zinc increased the wear rates at one or both test temperatures. The increase was especially marked in alloy No. 96 containing 88 per cent copper, 10 per cent tin, and 2 per cent lead, although the concordance of duplicate determinations was not so good as with most of the other alloys.

A second lot of castings was made of alloy No. 96 and, as in the first group, zinc increased the rate of wear. Microscopic examination showed no features to which the reversal in the effects of zinc could justly be ascribed. As is shown in Figures 22 (*a*) and 22 (*b*), a

reasonably uniform distribution of the lead particles was found, both in the alloys with and without zinc, and the structures in the two lots of each alloy were quite similar. (Figs. 22 (*c*) to (*f*), inclusive.) It may be significant that while more of the eutectoid was shown by the alloy with zinc in the second group of castings the opposite was true in the first group. (Figs. 22 (*c*) and (*d*).) This does not explain the differences in wearing properties, since in both groups the alloy with zinc showed the higher wear. However, it does indicate that the alloy under discussion is sensitive to casting conditions, and examination of Figure 12 will show that this composition is also in a field of rapidly changing wear rates.

Karr [10] showed that variations in the casting conditions might have an appreciable effect upon the properties of bronzes. Similarly, the fact that very marked changes in properties can be encountered as the result of relatively small differences in a variable, such as casting temperatures, is shown by the results reported more recently by Rowe [11] for an alloy containing 88 per cent copper, 6 per cent tin, and 6 per cent zinc.

When these effects are viewed in the light of the generally small changes produced by zinc over the greater portion of the field covered in the system copper-tin-lead, it would seem justifiable to draw the conclusion that the effects of zinc up to 4 per cent are small and may be insignificant in comparison with changes in properties quite readily produced from variations in the casting conditions.

While the foregoing comparisons of the wearing properties of the bronzes in the absence of lubrication are based on the weight losses per 10,000 revolutions, similar effects are shown when comparisons are based on the wear per unit of work. It was therefore unnecessary to include both sets of comparisons in this report.

It should also be noted that no measurable wear was produced on the steel specimens in any of the wear tests at atmospheric temperatures or 350° F. In most cases the steel specimens gained a little in weight through the adherence of bronze particles.

VI. SUMMARY

Based on hardness tests, Izod impact tests, repeated pounding tests, and wear tests, both with and without lubrication, at temperatures within the range 70° to 600° F., the bronzes in the copper corner of the copper-tin-lead system have been classified according to the character of service for which they seem to be best adapted.

Bronzes with less than about 4 per cent tin are unsuited for general bearing service, since they had low resistance to deformation and wore rapidly in the absence of lubrication. However, some of these alloys,

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[10] C. P. Karr, Standard Test Specimens of Zinc Bronze, B. S. Tech. Paper, No. 59; 1916.

[11] F. W. Rowe, The Effect of Casting Temperature on the Physical Properties of a Sand-Cast Zinc-Bronze, J. Inst. of Metals, 31, p. 217; 1924.

such as those high in lead, can serve satisfactorily for special service involving low loads.

Bronzes with less than about 5 per cent lead appear to be suited only for service where lubrication can be maintained. However, they are applicable with such a restriction to a wide range of service conditions depending upon the proportions of tin present. With low tin the alloys were tough but did not resist deformation as well as the bronzes high in tin.

Bronzes containing more than about 5 per cent lead are best able of any of the groups studied to operate for short periods in the absence of lubrication. Bronzes with 15 per cent lead are better in this respect than bronzes with 5 per cent lead, but there were no appreciable advantages apparent in raising the lead above about 15 per cent. In fact, some disadvantages were encountered in that the toughness was decreased in bronzes containing around 4 to 8 per cent tin. However, by varying the proportions of tin and lead in the bronzes of this group, varied mechanical properties can be obtained while maintaining good frictional properties.

The addition of 4 per cent zinc to the bronzes had, in general, a small influence upon the properties of the bronzes studied. With two exceptions such changes as were observed seemed beneficial rather than detrimental for bearing service, since they comprised a tendency toward higher hardness and resistance to deformation, lower friction, and lower wear in the absence of oil.

Further development of methods of test for wear in the presence of lubricants may show that zinc tends to increase the weight losses and duration of the "wearing-in" period of bronze bearings, but since this is also a function of the perfection of fit such effects would be disadvantageous only in certain cases. The addition of 4 per cent zinc did not appreciably affect the wear rates subsequent to the "wearing-in" period.

In general, the results seem to justify the conclusion that the effects of zinc up to 4 per cent are generally small and may be insignificant in comparison with changes in properties quite readily produced in bronzes from variations in foundry practice. This should not be construed to apply to additions of zinc when other impurities are present.

VII. ACKNOWLEDGMENTS

Acknowledgment is made to H. K. Herschman, associate metallurgist, for the micrographs, and to E. R. Darby, metallurgist, The Bunting Brass & Bronze Co., for his cooperation throughout all phases of the work.

WASHINGTON, November 1, 1928.